Scattering of CO_2 laser radiation on tin plasma targets

V.V. Medvedev[1,2,3], V.V. Ivanov[1], V.M. Krivtsun[1], K.N. Koshelev[1], V.Ye. Banine[4] and A.M. Yakunin[4]

1 Institute of Spectroscopy, Troitsk, Moscow reg., Russia

2 FOM Institute for Plasma Physics, Nieuwegein, Netherlands

3 Moscow Institute of Physics and Technology, Dolgoprudny, Moscow reg., Russia

4 ASML, Veldhoven, Netherlands.

Introduction

Effective coupling of laser radiation to plasma is essential for achieving high conversion efficiency of LPP based EUV sources. Among other drawbacks, poor coupling may result in high reflectance of plasma, which causes laser radiation propagation into the litho system resulting in heating of the optical elements and wafer.

It was well established that modification of target's geometry (split droplets, cavity targets etc.) and focal spot size allow noticeably increase laser radiation absorption and conversion efficiency [1,2]. The underlying mechanism consists in manipulating rate and geometry plasma expansion which determines gradients of the electron density and surface of the critical plasma density.

In our work we study dynamics of the electron critical density surface for different types of tin targets heated by CO_2 laser. Evaluating spatial distribution of plasma permittivity we calculate indicatrix of scattered laser radiation.

References

[1] S. Fujioka et al. *Appl. Phys. Lett.* **92**, 241502 (2008)

[2] S. Yuspeh et al. *Appl. Phys. Lett.* **93**, 221503 (2008)

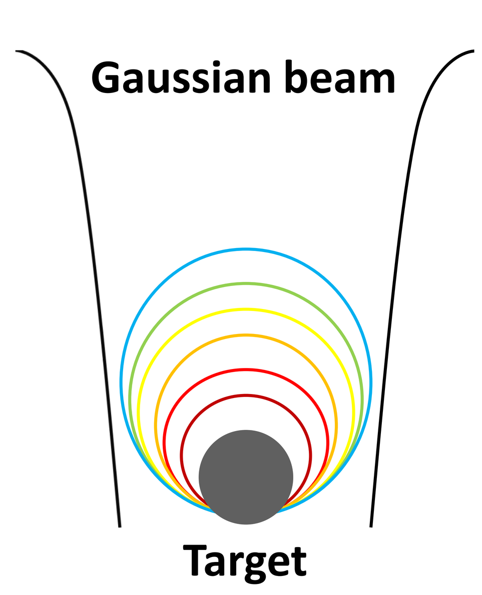
Model

Targets

Two targets were examined. 1) Spherical tin spherical droplet of 30 um diameter. The value of the diameter was chosen in accordance with minimum-mass target principle. 2) Split target was modeled by concentric toroidal rings in order to save the RZ-geometry. Number of the rings determines total mass of the target which is taken equal to the spherical droplet.

In the model targets were irradiated by gaussian laser beam.

LPP scheme



Laser parameters

Laser wavelength 10.6 μm

- Pulse energy 0.4J
- Pulse time shape: Gaussian

$$I(t) \propto \exp\left[-\left(\frac{t-2\tau}{\tau}\right)^2\right], \quad \tau = 120\,ns$$

- Focal spot 200 μm: Gaussian distribution of field

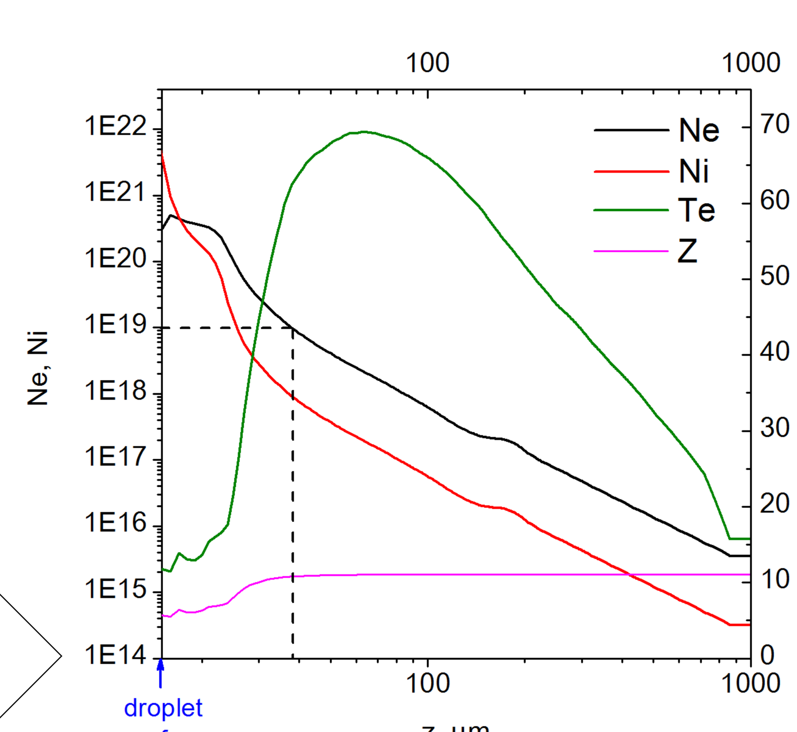
$$I(r) \propto \exp\left[-\left(\frac{r}{R}\right)^2\right]$$

$R = 70$ μm

Plasma expansion and radiation transport

The two-dimensional (RZ-geometry) radiative MHD plasma code [3] was used to model the emission dense tin plasma. The code was used to obtain emission spectra and plasma parameters such as ion and electron density, its temperature.

Figure shows plasma parameters for the 30 um droplet.

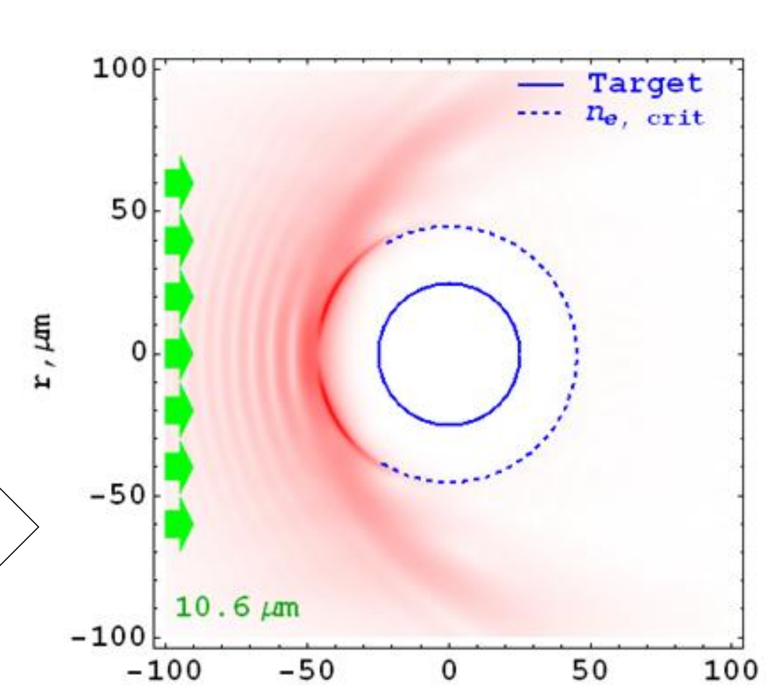


[3] V. Novikov et al. High Energy Density Physics, **3**, 198 (2007)

Laser absorption and scattering

Interaction of laser light with plasma was performed by numerical solving of Maxwell equations using FDTD method. RZ-profiles of dielectric permittivity were calculated from plasma parameters (Ne, Ni and Te) using model of Drude.

Figure shows spatial distribution of the absorption coefficient for 30 um droplet.

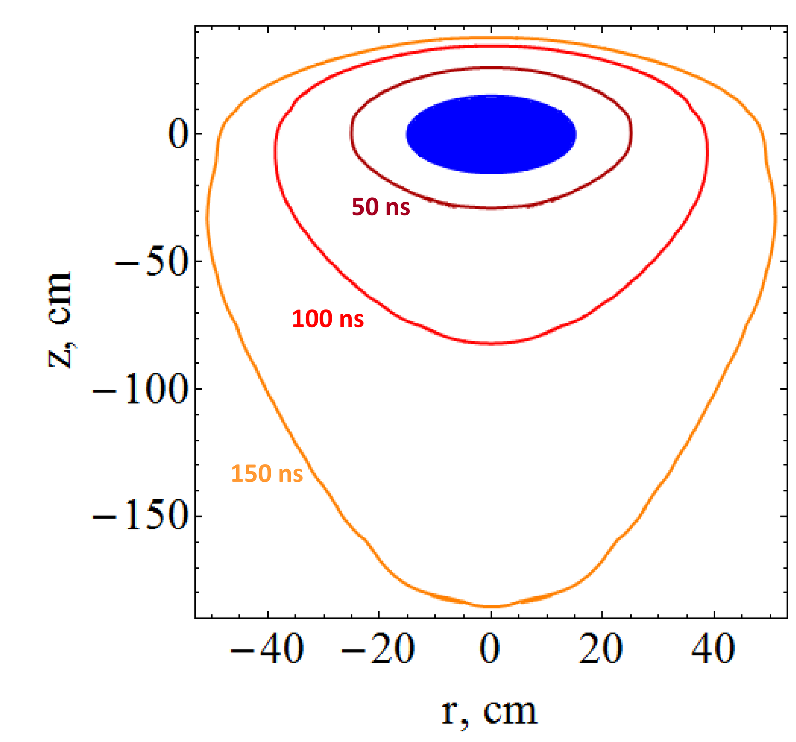


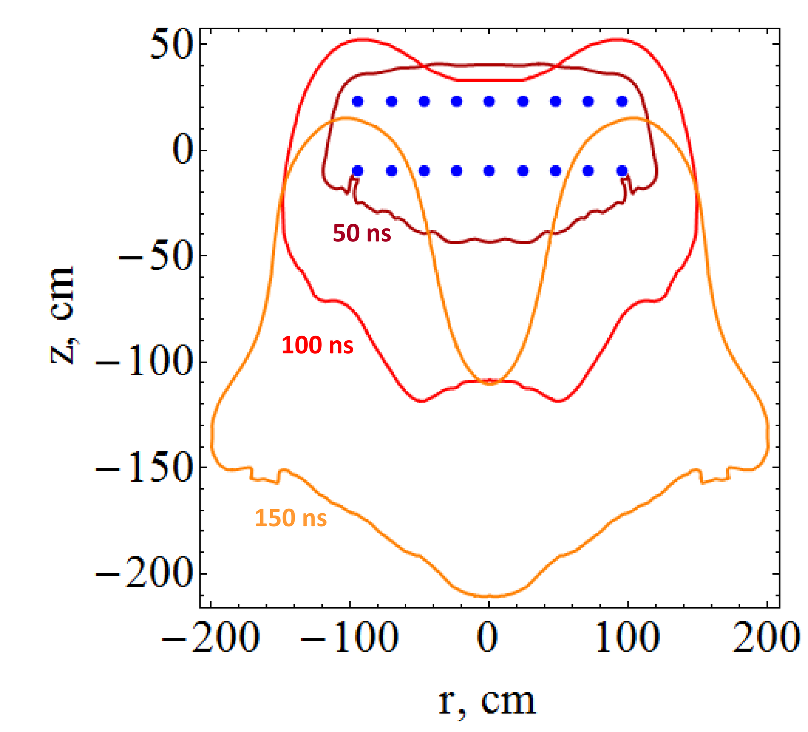
The most intensive absorption takes place near critical surface

Results

Dynamics of the electron critical density surface: Ne = 10^{19} cm^{-3}

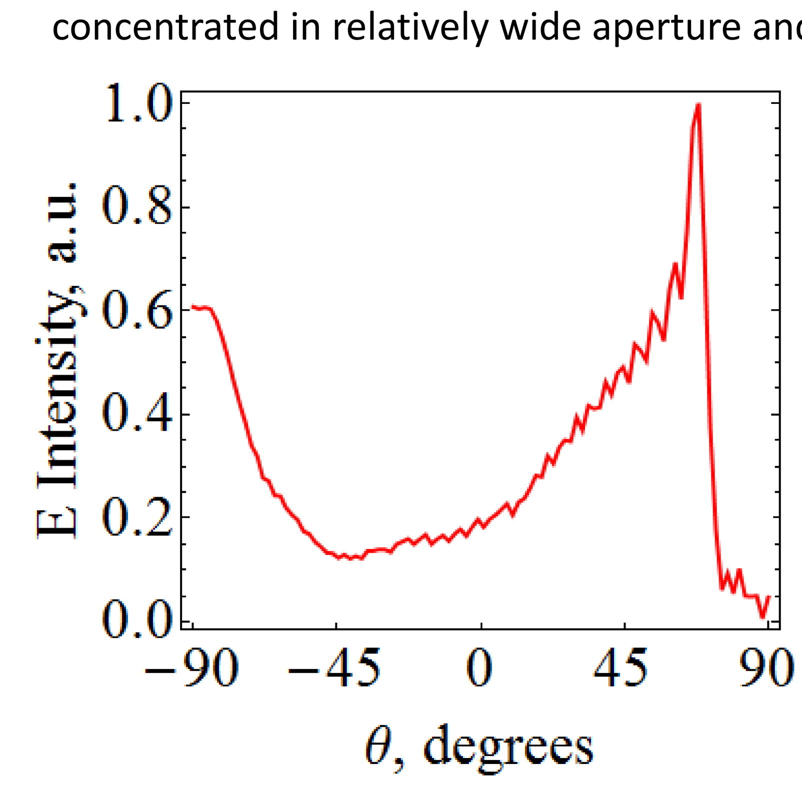
Figures below show RZ-contours of the surface for the successive time moments. Laser beam direction is opposite to that of z-axis. In case of the spherical droplet critical surface tends to stationary configuration in the region of laser irradiation. In case of the split target solid fuel burns out efficiently, what causes essential transformation of the critical surface.

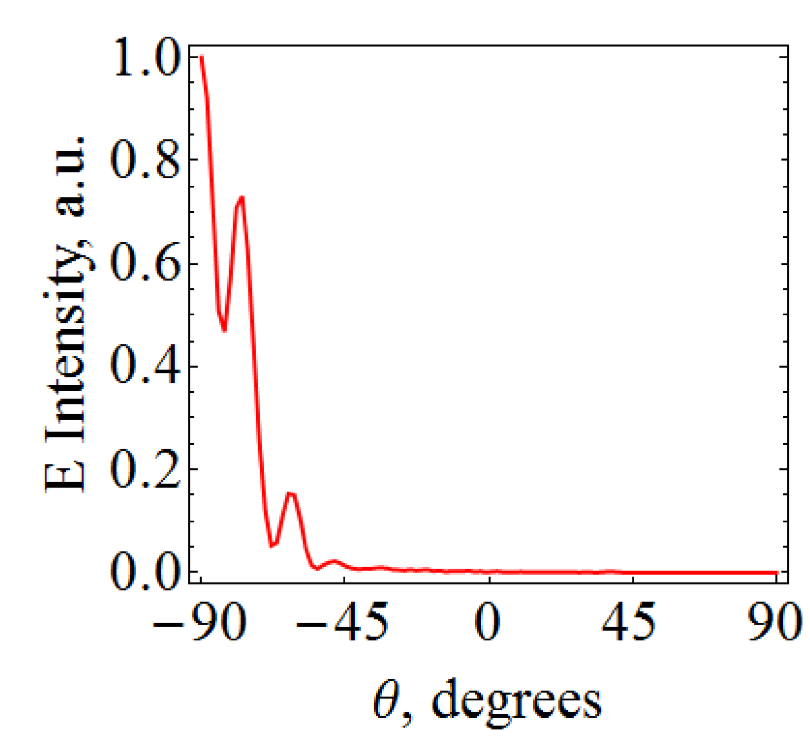




Angular distribution of scattered radiation

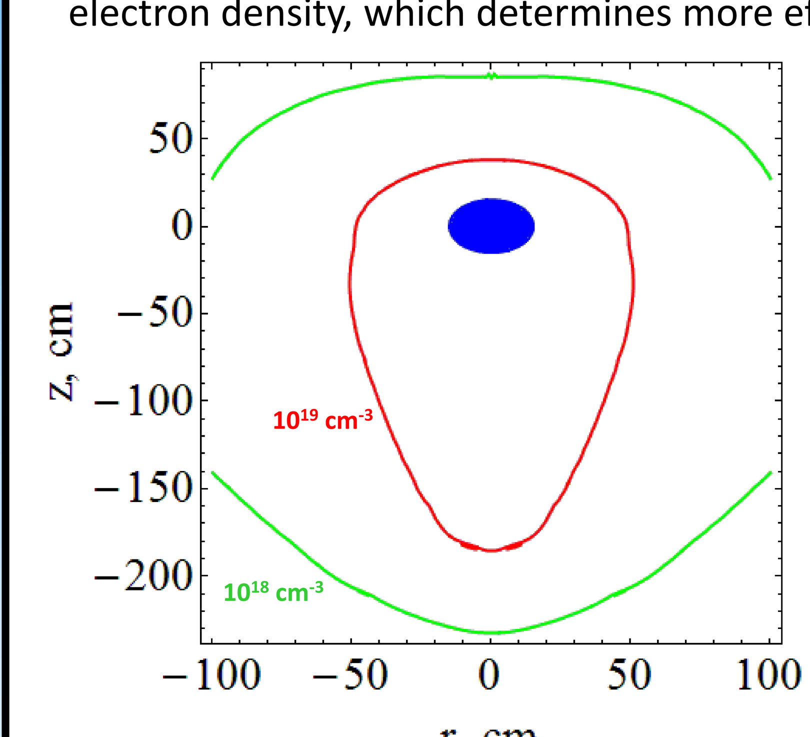
Figures below show indicatrixes of scattered CO2 laser radiation for the time moment of laser pulse maximum. Angle of 90° corresponds to the direction of the laser beam. In case of single droplet significant portion of the incident radiation is scattered forward with about 20° deviation from the beam direction. In case of split target all scattered radiation is concentrated in relatively wide aperture and directed backward.

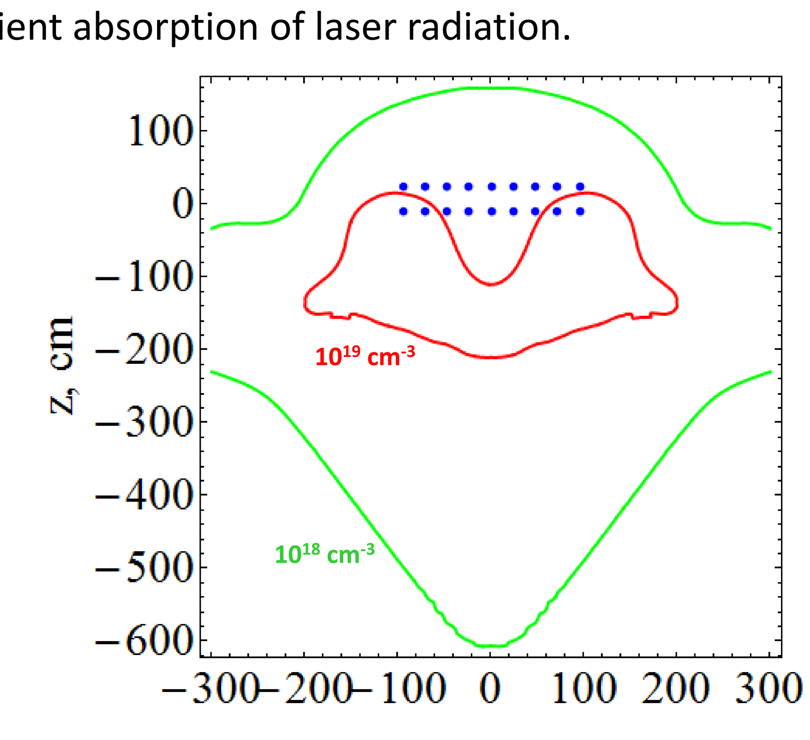




Gradient of the electron density

Figures below show RZ-contours of the surfaces with fixed electron density 10^{18} cm^{-3} and 10^{19} cm^{-3} (critical density). In case of split target its burning-out causes smoother gradients of electron density, which determines more efficient absorption of laser radiation.





Conclusions

- ❑ **Droplet targets scatter the greater part of incident radiation. Split targets appears to be more efficient absorbers of laser radiation.**
- ❑ **Direction of scattered radiation is strongly dependent on the target's geometry. Spherical droplet shades laser beam direction and the most part of radiation is scattered at directions between 20° and 50° to the beam. Split target scatters radiation back.**

International Workshop on EUV Sources, Dublin, Ireland, November 13-15, 2010

Contact Information: Viacheslav Medvedev, medvedev@isan.troitsk.ru